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The Effect of Various Frequencies and Durations of Flexibility Training upon Hamstring Range of Motion

Amira El-Dabh Ranney
Ithaca College

THE EFFECT OF VARIOUS FREQUENCIES AND DURATIONS OF FLEXIBILITY TRAINING UPON HAMSTRING RANGE OF MOTION

by

Amira El-Dabh Ranney

An Abstract

of a thesis submitted in partial fulfillment

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Thesis Advisor: Dr. G. A. Sforzo

ABSTRACT

Despite the documented need for flexibility training, little research has been done on the effects of varying frequency and duration of stretching on flexibility. The purpose of this study was to examine the effects of a selected combination of frequencies and durations of stretching on hamstring muscle flexibility. Static self-stretching was performed for 4 weeks by 36 college-aged, female subjects. One leg of each subject received the stretching treatment, while the contralateral limb served as the control. The experimental design was a 3 x 4 factorial consisting of frequencies of two, four, or six times per week and durations of 30, 60, 90, and 120 s. Flexibility was measured passively by both a straight leg raise test and a knee extension test 1 day prior to and 2 days after the training period. An analysis of covariance was performed to evaluate the influence of duration and frequency upon posttraining flexibility after adjustment for differences in initial flexibility. Results obtained from the straight leg raise test data displayed a significant linear relationship between posttraining flexibility and frequency of training such that a 1.75° increase in flexibility resulted for each additional day of stretching per week. No significant influence of duration upon posttraining flexibility was found for the range of durations studied. The knee extension data revealed no significant effects of frequency or duration on posttraining flexibility. It was believed the stretching exercise used during the training period of this study was more

specific to the muscles involved during the straight leg raise test than the knee extension test, possibly accounting for the discrepancy between these results. In conclusion, these results indicated that within the range of frequencies and durations examined, frequency of training was the primary factor in determining increases in posttraining flexibility.

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A Thesis Presented to the Faculty of
the School of Health, Physical
Education, and Recreation
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Requirements for the Degree
Master of Science

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by
Amira El-Dabh Ranney
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Ithaca College
School of Health, Physical Education, and Recreation
Ithaca, New York

CERTIFICATE OF APPROVAL

Master of Science Thesis

This is to certify that the Thesis of
Amira El-Dabh Ranney
submitted in partial fulfillment of the requirements for the degree of Master of Science in the School of Health, Physical Education, and Recreation at Ithaca College has been approved.

Thesis Advisor: ____________________

Committee Member: ____________________

Candidate: ____________________

Chairman, Graduate Programs in Physical Education: ____________________

Dean of Graduate Studies: ____________________

Date: 12.21.87

This thesis is dedicated to my husband, Tom,
for his help, support, and patience
throughout this project.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

INTRODUCTION

Stretching exercises to increase flexibility are often used by athletic trainers, exercise physiologists, physical therapists, physical education teachers, fitness leaders, coaches, and athletes. According to some authors, adequate flexibility may be important for the prevention of injury (Arnheim, 1985; Beaulieu, 1980; Holland, 1968; Schultz, 1979) and for the prevention of orthopedic problems (Cotten & Waters, 1970; Kisner & Colby, 1985). Stretching may also help to attain maximum athletic performance (Arnheim, 1985; Cornelius, 1981; Cureton, 1941; Holt, Travis, & Okita, 1970) and to reduce or prevent muscle soreness (deVries, 1962; McGlynn, Laughlin, & Rowe, 1979; Prentice, 1982). Lastly, stretching is often used in rehabilitation to restore or preserve function, prevent deformity, and improve posture (Licht, 1976; Medeiros, Smidt, Burmeister, & Soderberg, 1977; Tanigawa, 1972).

The mobility and flexibility of the soft tissues surrounding a joint must be adequate for normal range of motion (Kisner & Colby, 1985). These soft tissues include muscle, connective tissue, and skin. It appears that the major structure restricting joint motion, in normal conditions, is connective tissue (Barnes, 1984; Crosman, Chateauvert, & Weisberg, 1984; Holland, 1968; Lehmann, Masock, Warren, & Koblanski, 1970; Sapega, Quedenfeld, Moyer, & Butler, 1981). Pathological conditions may develop in connective tissue in the presence of injury, disease, or immobilization which can further limit the range of motion (Hepburn, 1985; Holland, 1968; Kottke, Pauley, & Ptak, 1966).

Connective tissue is composed of both elastic and collagenous fibers. In order to improve flexibility of the connective tissue the collagenous fibers must be lengthened. A stretch of the elastic fibers will result in a temporary increase only, with the fibers returning to their original length once the stretch is removed (Barnes, 1984; Hepburn, 1985; Kottke et al., 1966; Upledger & Vredevoogd, 1983). The best method to lengthen the collagenous fibers is presumably through the use of a low load, long duration static stretch. Several studies using such a stretch have displayed favorable changes in range of motion (Bohannon, Chavis, Larkin, Lieber, & Riddick, 1985; Lehmann et al., 1970; Light, Nuzik, Personius, & Barstrom, 1984). These studies, however, have all used different stretch durations and did not identify the minimum time needed to obtain a significant increase in flexibility. Additionally, the majority of these studies were performed on individuals with pathologic conditions. Two studies have addressed the issue of duration of stretch in individuals without pathology (Fox, 1984; Madding, Wong, Hallum, & Medeiros, 1987). Both of these studies found that a 15-s duration was adequate for obtaining an immediate increase in range of motion. The effects of different durations on the long term changes in flexibility have not been determined. The question of how often stretching exercises need to be performed has also not been adequately addressed in the literature. Numerous authors (Arnheim, 1985; Beaulieu, 1980; deVries, 1962; Kisner & Colby, 1985; Schultz, 1979) have suggested guidelines for the duration and frequency of stretching, but these suggestions have not been substantiated by research to this date. Through examining several different combinations of frequencies and durations of training, this study will attempt to establish appropriate frequency and duration guidelines concerning flexibility training in persons without pathology.

Statement of Problem

The purpose of this study was to examine the effects of a selected combination of frequencies and durations of stretching on hamstring muscle flexibility.

Scope of Problem

This study attempted to determine the appropriate duration and frequency to perform stretching exercises in order to accomplish significant improvements in hamstring flexibility. Stretching was performed for 4 weeks in individuals without any known pathology. For this purpose, 36 subjects were divided into 12 groups, with each group using one of the different possible combinations of three frequencies and four durations. No two groups received the same treatment. Supervised static self-stretching was performed to one hamstring group, while the other leg served as the control. Measurements were made of passive hamstring flexibility 1 day prior to training and 2 days posttraining to determine any chronic changes in flexibility. The data were analyzed to determine the effects of the various frequency and duration combinations upon chronic changes in muscle flexibility.

Hypotheses of Study

The following hypotheses concerning the duration and frequency of stretching were identified:

H_0: There will be no difference in the amount of flexibility obtained with different durations and frequencies of static self-stretching over 4 weeks of training as measured by the passive straight leg raise or knee extension test.

H_{R1}: The greater the duration of stretching during training, the greater the increase in flexibility realized.

H_{R2}: The more frequently a stretch is performed, the greater the increase in flexibility realized.

Definition of Terms

The following terms that were used in this study are defined here:

1. Flexibility: the ability of soft tissue structures surrounding a joint to yield to stretch and allow motion to occur.

2. Muscular end feel: a firm quality in the resistance to movement that an examiner feels when the subject is at the end point of a movement.

3. Self-stretching: a type of stretching exercise that the individual carries out himself or herself. The weight of

the body is used to apply the stretching force, and the amount of stretch is controlled by the individual.

4. Static stretch: a stretch using an external force, manual or mechanical, to increase flexibility. The stretch involves a held position, without movement.

Assumptions of Study

The following assumptions concerning this study were made:

1. Subjects stretched to the appropriate intensity and did not stretch too far or too little.

2. No acute stretching effects were present during posttraining measurement.

3. The person performing the measuring technique accurately assessed the muscular end feel.

Delimitations of Study

The following were the delimitations of the study:

1. All subjects (N = 36) were female volunteers between the ages of 18 and 21.

2. Subjects did not have any present pathologic condition that would affect hamstring flexibility and had no lower extremity injury within the past 6 months.

3. Static self-stretching was the only stretching technique used.

4. Flexibility was assessed passively by the straight leg raise and knee extension tests.

5. Training durations were 30, 60, 90, and 120 s.

6. Training frequencies of two, four, and six times per week were used.

7. Flexibility training was performed for 4 weeks.

8. Two repetitions of each stretch were performed per session.

Limitations of Study

The following were the limitations of the study:

1. Results apply only to female subjects between ages 18 and 21.

2. Results apply only to persons without present pathology or recent pathology that could affect hamstring flexibility.

3. Results apply only to performing static self-stretching.

4. Results apply only to flexibility as measured by the passive straight leg raise and knee extension tests.

5. Results apply only to the durations and frequencies used in this study.

6. Results apply only when 4 weeks of training are used.

7. Results apply only when two repetitions of each stretch are performed.

Chapter 2

REVIEW OF RELATED LITERATURE

This chapter will review the literature pertinent to flexibility and will include the following sections: (a) factors influencing flexibility, (b) exercises to enhance flexibility, (c) measurement of flexibility, and (d) flexibility training.

Factors Influencing Flexibility

Flexibility, or the range of motion of a joint, is influenced by the bone structure of the joint; the amount of muscle mass or fat surrounding the joint; the extensibility of the muscles, ligaments, tendons, and skin which cross over the joint; and the temperature of the soft tissue structures surrounding the joint. In any one or more of these factors, changes that can alter the flexibility of a joint can occur (Wilmore, 1982; Wright, 1973). Muscle and connective tissue are generally the target structures when trying to increase flexibility of a joint (Kisner & Colby, 1985).

There is much controversy over which structure primarily limits joint mobility. Stolov and Weilepp (1966) pointed out that muscle is not a homogeneous substance and its length-tension characteristics are formed from a combination of elements. These included nonpathologic adhesions between a muscle belly and its adjacent muscle, overlying skin, and subcutaneous tissue; the epimysium, perimysium, and endomysium; the sarcolemma; the contractile materials of actin and myosin within the muscle fibers; and the associated tendons. The authors stated that the relative contribution of each element to stiffness is unknown. Other authors (Kisner & Colby, 1985; Lamb, 1984; Licht, 1976) have noted that range of motion is limited by muscles, tendons, ligaments, and skin, but none discussed the order of importance of these structures in limiting motion.

Several studies have been performed to determine if it is muscle or connective tissue that first limits mobility. Johns and Wright (1962) performed experiments on the metacarpophalangeal joints of cats (which are similar in size and function to the same joint in man). Stiffness was measured as the amount of torque needed to produce passive motion at the wrist. Each successive layer of tissue was cut to be able to attribute stiffness due to skin, muscles, tendons, and the joint capsule. They found that these various tissues limited flexibility in different manners dependent upon the wrist's position in the range of motion. In midrange the joint capsule provided the primary limitation to motion, with the muscle providing the next limitation, and the tendon providing the third. DeVries (1966) used these original data to calculate what the limiting structures would be at the end ranges of flexion and extension. He showed that at end ranges the muscle is the primary limiting factor, the capsule second, and the tendon still third.

Cummings (1984) compared muscle to other soft tissues that limit elbow extension. His hypothesis was that if muscle normally limits extension, then paralysis should allow greater extension to occur. Paralysis of elbow extension was obtained through a myoneural blocking agent. Results revealed that elbow extension was greater in all subjects when the muscles were paralyzed. Therefore, it was concluded that muscle is the structure that causes the initial limitation of extension.

Experiments also have been performed on the skeletal muscles of frogs to determine the structures limiting motion. Sichel (1941) examined the extensibility of frog adductor fibers. He prepared the fibers so that the sarcolemma was left without the fibrillar material. He termed this an "empty" sarcolemma. Fibers were stretched, and the elongations of the normal and "empty" segments were compared at the same tensions. The "empty" sarcolemma displayed elongations an average of 2.2 times longer than the intact segment. It was therefore concluded that the contractile component of the fibers was the significant contributor to resistance to stretch. Casella (1951) agreed with this finding through his study on frog skeletal muscles and stated that the sarcolemma contributes only a small portion to the tensile force of the resting fiber.

An experiment was performed by Stolov and Weilepp (1966) to examine the passive length-tension diagram of whole muscle and muscle with cut epimysium to determine the contribution of the outer connective tissue sheath and the tendon in the normal and denervated rat gastrocnemius. They found that the epimysium supported only a small amount of tension in the normal and denervated gastrocnemius and that the tendon was essentially rigid during the passive extension.

In summary, several authors have shown muscle to be the primary limiting factor to full range of motion. Studies performed on the contractile components of muscle in frogs and rats have determined this to be the cause of resistance to stretch.

In contrast to these findings, many authors have stated that it is connective tissue that is the primary factor contributing to limited flexibility (Barnes, 1984; Holland, 1968; Sapega et al., 1981). There are numerous forms of connective tissue. These include tendon, ligament, joint capsule, cartilage, and fascia (Cormack, 1984). Connective tissue is composed of collagenous and elastic fibers embedded in a protein-polysaccharide ground substance. The ground substance is an amorphous gelatinous material that serves to decrease friction between the fibers. The response of these tissues under load is influenced by the structural orientation of the fibers, the properties of collagenous and elastic fibers, and the proportion between collagenous and elastic fibers (Nordin & Frankel, 1980). Collagenous fibers are the most predominant, forming the bulk of fascia, tendons, and ligaments. Collagenous fibers can withstand high tensile loads and display little extensibility. Elastic fibers, conversely, will lengthen in response to stretch, but when the tension is relaxed, they will return to their shortened position (Cormack).

Connective tissue has been reported to be predominantly responsible for resistance to stretch. Ramsey and Street (1940) stated that the sarcolemma and adhering connective tissue caused the primary limit to motion. The connective tissue was described to be the major component also by Banus and Zetlin (1938) and Hill (1968). In examining connective tissue, Stolov, Fry, Ridell, and Weilepp (1973) conducted an experiment on the force needed to split normal and denervated rat soleus muscle along the longitudinal connective tissue planes. The purpose was to compare normal to denervated muscle on the physical characteristics of connective tissue and determine whether the connective tissue fibers or the ground substance caused the primary adhesive forces. Muscles were separated at a constant rate until longitudinal separation occurred. No muscle fiber rupture occurred along these connective tissue lines. Results showed only a slight increase in force needed to separate the denervated fibers. As atrophy secondary to denervation would cause a relative increase in connective tissue, the force needed for separation in the denervated muscle should be greatly increased. This slight increase was consistent with changes seen in the ground substance as reported for humans. It was concluded that it was not the endomysium causing the adhesive forces through its intertwining with muscle fibers, but the ground substance.

Connective tissue normally has limited mobility and allows for stretch to occur as the slack in the tissues is taken up (Upledger & Vredevoogd, 1983). Connective tissue will reorganize itself, shortening and thickening when not opposed by a stretching force, and thereby become less flexible. Joint and soft tissue mobility is maintained by normal movement of body parts through their full range of motion several times daily. The tension caused by this movement overcomes the progressive shortening property of connective tissue. In the presence of trauma, poor circulation, edema, pain, or immobilization significant reorganization can occur and additional pathologic types of connective can be laid down that further limit mobility (Barnes, 1984; Kottke et al., 1966; Sapega et al., 1981).

Several authors have supported this concept. In a study performed on cat soleus muscles (Tabary, Tabary, Tardieu, Tardieu, & Goldspink, 1972) passive length-tension curves were determined for muscles immobilized at different lengths. Muscles immobilized in the shortened position displayed decreased extensibility. They stated that this may be partly due to the shortening of the muscle fibers, but more likely due to the increase in connective tissue in the muscle belly as seen upon histological examination. Gossman, Sahrmann, and Rose (1982) reported that shortened muscles show steeper passive tension curves than normal. This may be due to a relative increase in connective tissue secondary to muscle tissue loss, which then reduces the extensibility of the muscle. Remodeling of the endomysium and perimysium also is shown to occur as each becomes thicker and further limits motion.

Connective tissue can also demonstrate the property of progressive lengthening under certain conditions. In order for this to be a permanent increase in length, the collagenous fibers must be affected, as they will maintain their new length even after the force is removed, whereas elastic will not (Barnes, 1984; Kottke et al., 1966; Upledger & Vredevoogd, 1983).

Tissue temperature can also affect joint mobility. Experiments that examined the effects of heating, warmup, or cooling upon range of motion have been documented (Cornelius & Jackson, 1984; Cotten & Waters, 1970; Henricson et al., 1984; Lehmann et al., 1970; Warren, Lehmann, & Koblanski, 1976). Lehmann et al. performed a series of experiments on the rat tail tendon. The purpose was to find the conditions that would produce a maximal increase in collagenous tissue extensibility and residual length. In the first experiment four sets of tendons were used, each consisting of an experimental group and a control group. The experimental group was loaded at 45 ^{o}C and the control at 25 ^{o}C. Each group was loaded at different levels of tension ranging from 0 gm to 73 gm. Results demonstrated that both heating and load alone were ineffective in producing tissue elongation. In the combination of stretching and heating, however, a significant length increase was seen at all loads. Next, they showed that a sustained stretch of 20 min was more effective in increasing length than a short duration stretch. They then examined constant loading in conjunction with heating. A greater length increase was seen in tendons that received heating during the stretch. Lastly, it was shown that a greater retention in length gain was seen in a group that had tension maintained while cooling.

Rat tail tendons were studied by Warren et al. (1976) to examine the effects of low load, long duration and high load, short duration stretch, and the effects of heating with load application. It was determined that less damage will occur if the collagenous tissue temperature is raised before stretch is applied, and maximum permanent lengthening will occur when a low force load is applied to produce slow elongation. They attributed this to a stretch of the nonelastic collagenous fibers.

The effect of heat and stretching in humans was explored by Henricson et al. (1984). The effects of heat alone, stretching alone, and a combination of the two on hip motion were studied. Measurements of range were made before treatment, immediately after, and 30 min after treatment. Heat was applied with a heating pad for 20 min. Stretching was performed with a modified contract-relax technique. In the combination treatment, heat was applied immediately before treatment. Results indicated that heat alone did not increase the range of hip motion. However, stretching alone did increase motion significantly, and the combination showed a trend for increasing posttreatment range slightly further. No control group was examined.

The use of some type of warmup to increase tissue temperature, hence tissue extensibility, has been studied. Cotten and Waters (1970) compared the use of four types of warmup activities on trunk, shoulder, knee, and ankle motion. The activities they termed to be warmups were calisthenics, static stretching, ballistic stretching, and hot showers. All four types of warmup activities were shown to increase extensibility significantly as compared to no warmup. Hot showers appeared to be the least effective of the methods. In 1966 Fieldman examined the effects of various levels of warmup exercises on hip joint flexibility. Subjects were tested once a week for 5 weeks. No warmup was initially used. On each subsequent visit increasing amounts of warmup exercises were used prior to measurement of hip flexion. It was shown that, as the exercises became more intense and were more related to the measured activity, subjects performed better. All types of warmup increased flexibility. It was concluded by both of these studies that a performance of some type of warmup to increase tissue temperature is beneficial prior to stretching.

One study examined the effect of the use of cold and stretching on hip extensor flexibility (Cornelius & Jackson, 1984). All subjects received 10 min of cold application prior to stretching. Subjects were then placed in two different types of proprioceptive neuromuscular facilitation stretching groups. One type of stretch produced a significantly greater increase in flexibility. The primary author had done a previous comparison of these methods without cold application and found no difference, therefore it was concluded that cold application is effective in enhancing flexibility. The lack of a control group during this study, however, makes the results questionable.

It is still uncertain whether it is the connective tissue or muscle that primarily limits flexibility. Most authors, however, presently state that connective tissue is the limiting factor and should be addressed in flexibility training (Barnes, 1984; Hepburn, 1985; Kisner & Colby, 1985; Sapega et al., 1981). Additionally, pathologic conditions may develop in connective tissue which can further limit mobility. Normal motion is maintained by the daily movement of joints throughout their full range of motion. This movement elongates and stretches the muscles, ligaments, tendons, joint capsules, and fascia. The force exerted by these movements overcomes the progressive shortening tendencies of the connective tissue and maintains normal range of motion. If normal motion is restricted for any reason, the connective tissue will reorganize and shorten, resulting in limited motion. Connective tissue responds to low force, long duration stretching through elongation. The use of heat before or during the application of this force enhances the amount of elongation. The application of cold for augmenting flexibility is questionable.

Exercises to Enhance Flexibility

There are several different types of stretching exercises that can be utilized in flexibility training. This section will describe the major types of static, ballistic, and proprioceptive neuromuscular facilitation exercises and discuss studies that have compared these exercises.

Static

Static stretching involves the use of nonpercussive, held stretching movements (Cornelius, 1981). DeVries (1962, p. 223) defined static stretching as a "method involving a held position with no movement, slow or fast, in which the body segments to be stretched are locked into a position of greatest possible length." Static stretching can use either manual or mechanical force to apply the stretching load. Some authors refer to this as a passive stretch (Beaulieu, 1980; Kisner & Colby, 1985). In static stretching the force can be applied by another person or done independently, with a person using his or her body weight to supply the force. In the latter case, it would be considered a static self-stretch (Kisner & Colby).

Ballistic

Ballistic stretching involves repetitive, vigorous, rebounding maneuvers. The force of the bouncing stretches the muscles. One potential drawback of ballistic stretching is that it can set off the stretch reflex and thus cause muscle contraction. When a muscle is stretched, the stretch reflex fires and prevents it from becoming overstretched. This reflex is sensitive to both static and quick stretches. However, if a muscle is stretched quickly, the resulting contraction is more forceful then if stretched slowly. In ballistic stretching, the contraction secondary to the stretch reflex will counteract the force of the stretching, resulting in more force needed to stretch, and a less effective stretch (Beaulieu, 1980).

Proprioceptive Neuromuscular Facilitation

Proprioceptive neuromuscular facilitation (PNF) is a widely used technique for increasing flexibility. PNF involves active inhibition of a muscle. Presumably, this inhibition allows minimal resistance to elongation of that muscle (Kisner & Colby, 1985).

There are basically two types of stretches performed using the principles of PNF. One method is termed contract-relax, or hold-relax. This method places the tight muscle, the agonist, in the lengthened position. The muscle is contracted isometrically against resistance for 5-10 s, then is relaxed and taken passively through the newly gained range. This technique is thought to work because after a muscle contracts, there is a brief period of relaxation. This prestretch contraction may cause firing of the Golgi tendon organs with subsequent reflex inhibition of the muscle. The second method is termed contract-relax-contract. In this method the agonist again performs an isometric prestretch contraction, but now the antagonist isotonically moves the limb through the newly gained range. This method is thought to work through the principles of successive induction and reciprocal inhibition. With successive induction the initial contraction of the tight muscle facilitates excitation of the antagonist to that muscle. Contraction of the antagonist now occurs with subsequent reciprocal inhibition of the tight muscle. In reciprocal inhibition, as a muscle isotonically contracts, its antagonist, the tight muscle in this case, is reciprocally inhibited so movement can occur. If the muscle contracts isotonically against resistance, even greater inhibition will occur (Cornelius, 1981; Kisner & Colby, 1985; Moore & Hutton, 1980).

The different types of stretching techniques have been compared in numerous studies. Two studies have compared static with ballistic stretching. Weber and Kraus (1949) had subjects perform either static or ballistic stretching to the low back-hamstring-gastrocnemius-soleus complex. This was performed for several months. Neither the exact number of months nor the frequency of performance was specified. Their results found ballistic stretching to be superior in terms of increased flexibility. DeVries (1962) compared static to ballistic stretching on the flexibility of trunk flexion, trunk extension, and shoulder elevation. It was found that both methods of stretching significantly increased flexibility in all three areas. DeVries concluded, however, that static stretches were preferable for several reasons. First, with static stretching there is less danger of stretching too far, because pain would be felt before tissue damage occurred. Also, static stretching takes less energy to perform. Lastly, where ballistic may cause muscle soreness, static stretching has been shown to possibly prevent and/or relieve muscle soreness.

PNF has frequently been compared to other techniques. The use of PNF techniques versus ballistic stretching has been examined in one study (Wallin, Ekblom, Grahn, & Nordenborg, 1985). After training three times per week for 30 days it was found that the group performing the PNF procedures had greater gains in flexibility. Tanigawa (1972) compared the contract-relax method to passive stretching on increasing hamstring length in a straight leg raise. Subjects were placed into either a PNF, passive, or control group. Each received stretching two times a week for 4 weeks. Results revealed the contract-relax procedure to be significantly more effective in increasing range of motion. This increase in range also occurred at a faster rate with the hold-relax technique. Tanigawa also stated this to be a better method of stretching because the technique uses an isometric contraction so there is no pain caused by movement. Due to this contraction, muscle strength is also being increased. Lastly, because the subject is participating in the procedure, it is psychologically healthier and there is less chance of injury.

All three techniques have also been compared (Etnyre & Abraham, 1986; Holt et al., 1970; Sady, Wortman, & Blanke, 1982). These studies have all found PNF techniques to be superior to either static or ballistic stretching in increasing range of motion.

Measurement of Flexibility

Instruments Used

Flexibility is often determined by measuring the range of motion of the joint that the structures in question cross. Some type of goniometric instrument is typically used. A goniometer essentially consists of a protractor with two arms. This is generally referred to as a universal goniometer. Pendulum, fluid, and electric goniometers also are used. One type of pendulum goniometer commonly known is the "Leighton Flexometer." The universal goniometer is the most common type used in clinical assessment (Miller, 1985).

Reliability. The reliability of goniometric measurement has been assessed in numerous studies. Reliability has been determined on the testers and on the device. Tester reliability can be divided into intertester and intratester. Intertester reliability refers to the tester's ability to reproduce another tester's measurement. Intratester reliability deals with a single tester's ability to reproduce his or her own measurements over time (Miller, 1985).

Intertester and intratester reliability using a universal goniometer were examined by Low (1976). He used 50 testers to measure one normal subject's wrist and elbow motion. Intratester reliability was found to be better than intertester. It was suggested that it is better to have one person make all measurements on the same patient. Boone et al. (1978) studied the tester reliability on assessment of six upper and lower extremity motions. Twelve normal male subjects were each measured by four testers. Subjects were measured one time weekly, each time by a different tester. Boone et al. also found intratester reliability to be better than intertester. Rothstein, Miller, and Roettger (1983) found both intratester and intertester reliability to be high on the measurement of patients with knee and elbow problems. They also found that when testers used the same test positions, intertester reliability was higher than when different test positions were used. Therefore, it was suggested that patient position should be described and kept constant when measuring joint motion over time. Gogia, Braatz, Rose, and Norton (1987) found intertester reliability to be extremely high in measurement of knee position.

Three of the above studies took three repetitions of each measurement and compared the reliability using an average of the three versus using only one measurement. Low (1976) found that the use of the average improved reliability, whereas both Boone (1978) and Miller (1985) found that averaging did not increase reliability.

In assessing device reliability, Leighton (1955) found the pendulum goniometer to be reliable for measuring the upper extremity, lower extremity, and spinal motion in normal subjects. Rothstein et al. (1983) showed that different types of universal goniometers were all equally reliable in measuring knee and elbow motion.

It has been suggested that larger scale increments on a goniometer will result in greater reliability (Wainerdi, 1952). Rothstein et al. (1983), however, found that rounding readings to the nearest 5° did not result in better reliability than not rounding. It was suggested that using a finely incremented scale actually results in more detail in measurement.

Validity. Studies determining the validity of goniometry are not as extensive as reliability studies. Ahlback and Lindahl (1964) found that their specific method of goniometric measurement of hip joint motion agreed closely with radiographic measurements. Gogia et al. (1987) assessed the validity of knee measurements taken with a plastic universal goniometer. The Pearson product-moment correlation coefficient was determined to be .97-.98. Measurements were compared with measurements taken from roentgenograms.

Based on the available data Miller (1985, p. 132) made several conclusions regarding measurement of joint motion. He stated that the universal goniometer is the "most reliable, versatile and clinically feasible instrument for assessing joint motion." The validity of these instruments is still somewhat unclear, but the point is made that they still provide a valuable basic indicator of the subject's status.

Measurement of Hamstring Flexibility

Several different methods have been used to assess hamstring flexibility. The straight leg test has often been used (Ekstrand, Wiktorsson, Oberg, & Gillquist, 1982; Hubley, Kozey, & Stanish, 1984; Koury, Mamary, Kagan, & Bourguignon, 1986; Markos, 1979; Moller, Ekstrand, Oberg, & Gillquist, 1985; Monroe & Overby, 1986; Sady et al., 1982; Tanigawa, 1972; Wallin et al., 1985). In this test the subject is placed in a supine position, with one hip flexed and the knee kept in extension. The leg is lifted until an end point in the range of motion has been reached. This can be done actively (Markos; Monroe & Overby) or passively (Ekstrand et al.; Fisk, 1979; Hubley et al.; Moller et al.; Tanigawa; Wallin et al.).

The end point in the range of motion has been determined several ways. Tanigawa (1972) raised the leg until a pull was felt in the popliteal fossa. Wallin et al. (1985) passively raised the leg until the knee began to flex. Fisk (1979) raised the leg until the pelvis was determined to have begun posterior rotation as noted by palpation. Most studies used some sort of stabilization on the opposite leg and pelvis to decrease the influence of pelvic and lumbar motion on readings. The opposite lower extremity was most commonly in an extended position, but was sometimes placed in a flexed position at the hip and knee, or flexed at the knee and extended at the hip.

Kendall, Kendall, and Wadsworth (1971) have long been proponents of the use of the straight leg raise for the measurement of hamstring flexibility. To perform the test they stress that the low back must be flat on the table with the opposite leg held down to stabilize the pelvis and prevent excessive flexion of the lumbar spine. The tested leg should then be raised passively, flexing the hip and keeping the knee in extension. They point out the important fact that if the back is not flat against the supporting surface a mismeasurement can be made. This is because if the back is arched, the hamstrings are already placed on a stretch proximally. If the back does not naturally lie flat, the opposite hip should be flexed until the back is flat on the surface, then stabilized in this position.

Several studies have been performed to assess the straight leg raise test. Intratester reliability during different sessions using this method was examined by Ekstrand et al. (1982). They found this to be high. Fisk (1979) looked at intertester reliability. He also found this to be good, as the maximum reading difference among three therapists on any measure was only 3^{o}. He did not use any statistical analysis to support this, however.

As mentioned, most authors stated that the leg opposite to the test leg and/or the pelvis needs to be stabilized during testing to prevent pelvic and lumbar spine motion from affecting the test accuracy. In an interesting study performed by Bohannon (1982) cinematographic analysis displayed that the commonly suggested methods for stabilizing the pelvis do not prevent pelvic motion. He suggests that this test is therefore not a valid indication of hamstring length.

Another measurement of hamstring flexibility involves extending the knee when the hip is fixed at 90° with the subject in a supine position. This method performed passively is the suggested method for measurement as described by Hunt (1985). In a study performed by Gajdosik and Lusin (1983) the use of this type of active knee extension test was examined. Healthy subjects were tested twice on each leg at 1/2-hour intervals by the same examiner. They were placed supine, and the nonmeasured leg was strapped to the table. The pelvis was also stabilized by securing it to the table. A pendulum goniometer was used for measurement. The hip was flexed to 90°, and the subject kept it in this position by maintaining his thigh in contact with a wire placed above them. The subject then straightened his knee until the point of mild initial resistance. Movement beyond this point caused a mild myoclonus. The intratester correlation coefficient for test and retest measurements was .99, displaying a high degree of reliability. A modification of this method was used by Fox (1984) in measuring hamstring tightness prior to and after performing a set of stretching exercises. Reliability in his study was also found to be high.

Both the straight leg raise and knee extension test are used widely for testing hamstring tightness. Both have been shown to be reliable methods. The validity of the straight leg raise has been questioned, and validity has not yet been established for the knee extension test.

Flexibility Training

In the studies performed on flexibility training many different protocols have been used in terms of duration of the stretch and frequency of performance. This makes results difficult to compare and does not provide information on optimal levels of these parameters. Duration of static stretches included 5-, 6-, 9-, 20-, 30-, and 60-s holds (deVries, 1962; Etnyre & Abraham, 1986; Hartley-O'Brien, 1980; Holt et al., 1970; Markos, 1979; Tanigawa, 1972). Duration of PNF stretches included 5-, 6-, 9-, and 20-s holds (Holt et al.; Markos; Sady et al., 1982; Tanigawa). Frequency of training varied from 2 to 3 to 7 days per week (deVries; Hartley-O'Brien; Medeiros et al., 1977). Total training session periods included 8 days or 3, 4, or 6 weeks (Holt et al.; Sady et al.; Tanigawa). None of these studies discussed why they picked the given durations, frequencies, or lengths of training, however, these choices used in performing the static stretches are somewhat consistent with several published guidelines. Beaulieu (1980) suggested holding the stretch for 10 to 60 s and stated the frequency should be daily, or a minimum of four times per week. DeVries (1986, p. 471) stated that "positions should be held for 30 to 60 s for best results." This duration has been supported by Arnheim (1985), who also added that exercises should be done several times daily. Lastly, Anderson (1980) instructed that stretches should be held 20 s. Although these authors stated these times as the best to achieve maximum stretch, none of them cited references to support these guidelines. The authors also did not discuss the length of the training session needed before increases in flexibility will be obtained.

In addressing the duration of the passive stretch several authors have taken into consideration that a low load prolonged stretch has been shown to result in the most significant lengthening in the connective tissue, with the least damage (Warren, Lehman, & Koblanski, 1971; 1976). As a result, Sapega et al. (1981) suggested holding stretches for 20 min. Kottke et al. originally made this suggestion in 1966. Neither of these studies provided documented evidence of the effectiveness of this duration. Bohannon (1984) and Light et al. (1984) provided documentation on the effectiveness of prolonged loading. Bohannon used 8 min of loading and Light et al. used 60 min. Light et al. compared this duration with 1 min. Bohannon did not make any comparisons. As a result, it is difficult to draw inferences as to the minimum amount of time needed to affect flexibility. The durations used in these papers are also not practical in terms of an individual using stretching exercises in conjunction with enhancing athletic activity.

Only two studies have looked at duration, making comparisons among times more commonly used. Durations of 15 s, 45 s, and 2 min of passive hip abduction stretch were examined by Madding et al. (1987). The 72 normal male volunteers were divided into three treatment groups and one control group. Each subject's abduction range and resistance to stretch (measured by a dynamometer) of the left leg were taken prior to and following stretch. Acute hip abduction range was significantly increased in all three treatment groups. No difference existed among the groups, except a slight decrease in range between the 15-s and 45-s groups. The authors were unable to sufficiently explain this decrease. No differences among the three groups were seen in resistance to stretch following treatment. They concluded that 15 s is a reasonable duration to hold a stretch when immediate increases are desired. Only the acute effects were examined by this study, and it is not known which duration would result in long lasting increases in range of motion.

Fox (1984) examined 12 subjects treated once a week for 6 weeks. Each week a different duration was used in the stretching exercises until each subject had received each duration once. Durations consisted of 5-, 15-, 30-, 60-, and 120-s. Each subject performed a series of four stretching exercises designed to affect the hamstrings, each performed once. Flexibility was assessed immediately before and after each session, with acute changes in flexibility noted. Measurements of hamstring flexibility were done actively using a modified Gajdosik and Lusin (1983) method. It was stated that subjects extended their knee to the point of "maximum knee extension" (p. 51); it was not stated how this end point was determined. Results showed that a 5-s hold produced no significant gains whereas a 15-s hold significantly increased flexibility. The 30- and 60-s durations also produced significant gains, but these were not different from 15. The 120-s duration also produced a gain that was significantly different from all except the 60-s duration. It was concluded that if time is not a factor, 120 s should be used for stretching. If time is a factor, 15 s was recommended as sufficient. This concurs with the above study in that 15 s also produced a significant gain. In the previous study however, 120 s was not more beneficial than 15 s.

Like duration, the concept of frequency of training to increase muscle flexibility has not been extensively studied. As part of an experiment comparing the effects of PNF to ballistic stretching, Wallin et al. (1985) incorporated an evaluation of the frequency needed to maintain and increase range of motion. Subjects who had initially trained with PNF techniques for 30 days, three times per week, then trained for either one, three, or five times per week. One time a week was determined to be enough to maintain flexibility, whereas three and five times increased it further. McIntyre (1987) investigated the minimal time needed for maximal training effects to increase and maintain ankle joint range of motion.

Subjects were stretched either two, three, or four times per week. All three groups displayed significant gains. No difference was seen among groups.

Summary

Only a few studies have addressed the question of appropriate duration and frequency in performing stretching exercises. However, many authors have suggested guidelines for these stretches without substantial documentation of their efficacy. Most authors have arrived at duration times based upon past data that longer stretches will better affect the connective tissue, the tissue commonly thought to primarily limit flexibility. It is unclear upon what they base their suggestions for frequency.

Based also on this theory several studies have examined the effects of prolonged loading. This has been shown to be beneficial. Most of these prolonged times have been suggested in reference to individuals with decreased range of motion secondary to pathology. In the one study that addressed normal individuals, a duration of 8 min was used. This was not compared to shorter durations. In examining more commonly used durations, 15 s has been shown to be effective for improving flexibility. These studies have not examined the effects on flexibility over time or with training. Frequency studies have shown 2, 3, 4, and 5 times per week all to be beneficial for increasing range of motion. Data conflicts on whether increasing the frequency results in any further increase in range of motion. Research to date has not provided conclusive answers to these questions of appropriate duration and frequency to use in flexibility training.

Chapter 3

METHODS AND PROCEDURES

This chapter will review the methods and procedures used within this study and will include the following categories: (a) selection of subjects, (b) measurement of flexibility, (c) treatments, and (d) data analysis.

Selection of Subjects

Thirty-six female volunteer subjects were solicited from freshmen, sophomore, and junior physical therapy students attending Ithaca College in the spring of 1987. The age range was from 18 to 21 years old with a mean of 19.8 years. Height ranged from 154 to 176 cm with a mean of 166.9 cm, and weight ranged from 44.0 to 74.2 kg with a mean of 57.9 kg. Eight of the subjects participated in a regular exercise program, but they were not involved in any stretching exercises in conjunction with the exercise. Occasional spontaneous exercise was reported, but was not considered recent or vigorous enough to significantly affect the daily stretching. None of the subjects were involved in competitive sports, and all were free from lower extremity injury in the previous 6 months.

Measurement of Flexibility

Subjects reported 1 day prior to the beginning of the training program for measurement of flexibility. Flexibility was again measured for each subject 2 days after the last session, excluding the possibility of changes seen due to an acute stretching effect. Room temperature ranged from 21.4 ^{o}C to 24.0 °C during the testing days. Subjects were measured within the same 3-hour time block after training as they were before training.

On the first visit each subject read and signed an informed consent form (Appendix A). Height and weight were then taken. The subject's dominant leg was also determined at this time by pushing the subject off balance in a forward direction and seeing which leg she used to catch herself. Subjects were then asked with which leg they preferred to kick and if they were right or left handed. For 6 of the 36 subjects, the three criteria did not signify the same leg as dominant. On these subjects, the method of pushing off balance was used to determine dominance.

Hamstring flexibility was determined through two methods. No warmup was performed prior to testing. The right leg was tested first on all subjects for each technique. Three repetitions of each measurement were made, and the mean of the three was used as the measure of flexibility. The two techniques included a passive straight leg raise test and a passive knee extension test. The straight leg raise test was performed first on each subject.

Passive Straight Leg Raise Test

The subject was positioned supine on a plinth 61 cm wide and 190 cm long. Both legs were extended, and the arms were crossed over the chest. If the low back did not lie flat in this position the left lower extremity was flexed until the low back was flat on the surface. A strap was then placed across the anterior superior iliac spines and around the plinth to stabilize the pelvis. Small pieces of white tape were then placed as markers on the subject's greater trochanter, lateral epicondyle, and lateral malleolus of each lower extremity. The subject was then instructed to relax as one examiner raised the right lower extremity with the knee extended and the foot relaxed in plantar flexion. The lower extremity was raised until the tester determined an end range through a muscular end feel. This is described as a rubbery quality, or a firm resistance to movement, at the end of the available range of motion (Kessler & Hertling, 1983). At this point the tester determined the angle of the straight leg raise from horizontal with the use of a plastic universal goniometer. The axis was placed on the greater trochanter, with the moveable arm aligned with the lateral epicondyle of the knee and the stable arm parallel to the trunk. Accurate placement was checked by a second tester. It was determined that the stable arm was accurate by attaching a level to the stable arm. Readings were taken from the goniometer by the first tester only. The leg was then lowered, and the procedure was repeated two more times. The left leg was then tested in the same manner.

<u>Passive Knee Extension Test</u>

The subject was again positioned supine on the plinth, and the pelvis was stabilized to prevent excessive movement. The tape markers were checked to make sure they were still positioned correctly. The subject's right lower extremity was then flexed to a 90° angle at the hip. This placement was checked by the goniometer. The leg was then placed on a wooden box to insure that the hip remained in this 90° position. The knee was flexed and resting on the box, and the ankle was relaxed in plantar flexion. The left lower extremity was extended on the plinth. The second tester stabilized the left lower extremity and made sure the right hip did not deviate from the 90° position during testing. The subject was again instructed to relax, and the first tester raised the leg, extending the knee. The amount of maximum knee extension was again determined using a muscular end feel. This range was determined with the same goniometer. The axis was the lateral epicondyle, the moveable arm was in line with the lateral malleolus, and the stable arm was in line with the greater trochanter. A completely extended knee would have given an angle of 180°. The first tester placed and read the goniometer. Three measurements were taken, then the procedure was repeated on the left leg.

Treatments

The experiment was designed as a split-unit, repeated measures study. Each subject was considered an experimental unit with a treated and a control leg as subunits. The treated leg received the flexibility training. The treatment design was a factorial arrangement with three levels of frequency and four levels of duration. Subjects were placed into 1 of 12 different groups consisting of three subjects each. Groups included frequencies of two, four, or six times per week and durations of 30, 60, 90, or 120 s. Frequency placement was determined by subject availability, while duration placement was determined randomly through the use of a random numbers table. The groups involved in a frequency of two times per week reported for training on Monday and Thursday of each week; four times per week reported Sunday, Monday, Wednesday, and Friday; six times per week reported Sunday through Friday. All groups stretched for 4 weeks. Only the dominant leg was stretched, with the contralateral limb serving as the control. All stretching was supervised and occurred between 4:00 and 5:30 pm. In the event that a subject was unable to attend, she performed the stretching on her own during the same time frame. Room temperature ranged from 21.0 ^{o}C to 27.3 ^{o}C over the month of training.

On the 1st day of training subjects were given general instructions concerning training and instructions on how to stretch (Appendix B). These were verbally reviewed with them. They were also asked to fill out a physical activity log daily. This was to insure that subjects had not performed any physical activity immediately prior to stretching and had not performed additional stretching exercises or other exercises outside their normal schedule.

Each day that subjects reported for training they underwent the same routine. Prior to stretching all subjects performed 5 min of jogging in place as a warmup. Stretching was performed by having subjects place the leg to be stretched on a 74-cm-high plinth. They sat on the edge of the plinth with the other foot on the floor. The knee was held straight, with the foot relaxed and the toes and kneecap pointing straight towards the ceiling. Subjects were instructed to place both hands behind their head with elbows back as far as possible to assist in keeping the back extended. They then leaned forward holding their backs straight until a stretch was felt in the posterior thigh. Stretching was described as a mild pull. The stretch was then held for the designated duration. As the pulling feeling subsided during the stretch, subjects leaned farther forward until the same amount of stretch was once again felt. A 5-s rest was then taken in the upright position, followed by a repeated stretch. At completion subjects filled out a form showing where the stretch was felt and used a visual analog scale (Newton, 1986) to describe the amount of pain felt during the stretch (Appendix C). These methods were used in conjunction with observation to assure the subject was performing the stretch correctly and was not stretching too vigorously. Durations of stretching were timed using a digital stopwatch, and all subjects were instructed when to begin and stop stretching.

Data Analysis

Treatment effects were statistically analyzed using an analysis of covariance. Initial hamstring flexibility was used as a covariate for evaluating posttreatment hamstring flexibility. Linear contrasts were performed to evaluate linear and quadratic trends. Differences between adjusted least square means were evaluated by using _t_ tests.

Intratester reliability was determined during the pre- and posttraining measurement sessions using three replicate measurements of hamstring flexibility on both legs of the 36 subjects. A reliability coefficient was determined using an analysis of variance procedure based on the formula presented by Currier (1984):

$$R = \frac{MS \text{ between} - MS \text{ within}}{MS \text{ between}} .$$

Chapter 4

ANALYSIS OF DATA

Two types of measurement methods were used in this study, the straight leg raise test and the knee extension test. For each method, data were analyzed independently. The straight leg raise results are presented first, followed by the knee extension results. Reliability coefficients on repeated measures will also be presented.

Straight Leg Raise

An analysis of covariance was used to analyze posttraining flexibility. Initial flexibility scores were used as the covariate. The ANCOVA presented in Table 1 demonstrates that initial flexibility, leg (treatment vs control), and the frequency x leg interaction were all found to be significant. Because the frequency x leg interaction was found to be significant, simple effects for the treatment and control leg were evaluated. As there was no significant frequency x duration x leg interaction, simple main effects within each treatment were analyzed in all subsequent data analyses.

Specific linear contrasts were performed among the adjusted treatment means to further examine frequency and duration effects (Table 1). The linear contrast for frequency exhibits a significant linear relationship between frequency and posttraining flexibility. Figure 1 displays the main effect means for frequency on treatment and control legs and illustrates that posttraining flexibility on the treatment leg

Table 1

ANCOVA Results and Subsequent Linear Contrasts for Posttraining Straight Leg Raise Flexibility with Initial Flexibility

ANCOVA Summary Table

Source of Variance	Partial SS	df	MS	F
Frequency	106.12	2	53.06	1.19
Duration	20.45	3	6.82	0.15
Duration x Frequency	346.28	6	57.71	1.29
Error A	1070.76	24	44.62	
Initial Flexibility	95.13	1	95.13	10.44*
Leg (treatment or control)	320.78	1	320.78	35.21**
Frequency x Leg	201.89	2	100.95	11.08*
Duration x Leg	61.09	3	20.36	2.24
Frequency x Duration x Leg	31.17	6	5.20	0.57
Error B	209.53	23	9.11	

Linear Contrasts

Frequency				
Linear	293.72	1	293.72	32.24**
Quadratic	23.35	1	23.35	2.56
Duration				
Linear	10.20	1	10.20	1.12
Quadratic	2.90	1	2.90	0.32
Cubic	14.93	1	14.93	1.64

$^{*}p < .05$. $^{**}p < .01$.

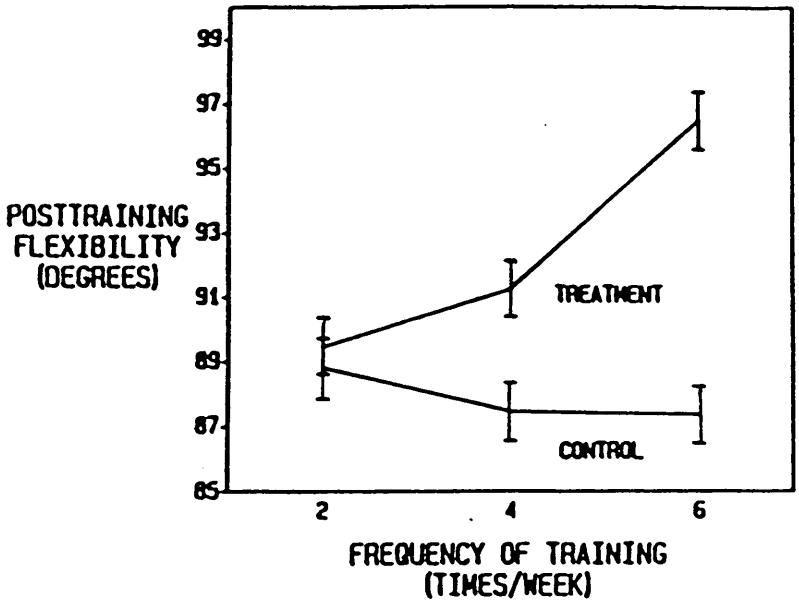


Figure 1. Frequency main effects for posttraining straight leg raise (n = 12).

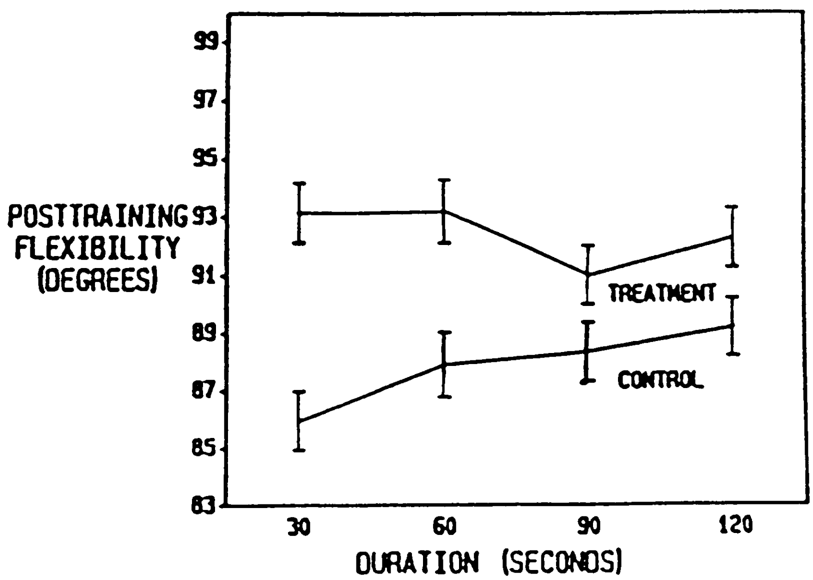


Figure 2. Duration main effects for posttraining straight leg raise (n = 12).

increases with increasing frequency. A linear regression performed on the adjusted treatment means gives an estimate of a 1.75° increase in flexibility for each additional day of training. No change was seen for the control leg.

Linear contrasts for duration show no significant effect on posttraining flexibility over the range of 30-120 s. Figure 2 demonstrates this and indicates that there is, however, a significant difference between the control leg (0 duration) and the treated leg across all levels of duration.

Tables 2 and 3 present adjusted means for simple and main effects for posttraining flexibility on treatment and control legs. Separation between main effect means was determined with individual _t_ tests. No significant difference existed between duration means for either the treatment or the control leg. For the treatment leg, a frequency of six times per week resulted in significantly greater flexibility than either the two or four times per week frequency.

Knee Extension

An ANCOVA performed on the knee extension data revealed no significant effects of any of the variables on posttraining flexibility (Table 4). Therefore, further analysis was not performed on the data. Tables 5 and 6 present nonadjusted means for the simple and main effects of treatment and control legs. Means were not adjusted as the covariate (initial flexibility) was not found to be significant.

Table 2

Adjusted Means for Simple and Main Effects for Treatment Leg Posttraining Straight Leg Raise Flexibility

Duration (seconds)	Frequency (times/week) 2	4	6	Main Effect M for Duration
30	90.14	92.98	96.33	93.15
	(1.78)	(1.77)	(1.75)	(1.04)
60	91.56	92.01	96.04	93.20
	(1.90)	(1.75)	(1.81)	(1.10)
90	84.67	93.35	94.89	90.97
	(1.74)	(1.75)	(1.90)	(1.01)
120	91.53	86.69	98.63	92.29
	(1.78)	(1.77)	(1.81)	(1.01)
Main Effect M	89.47	91.26	96.48*	
for Frequency	(0.89)	(0.87)	(0.89)	

Note. Standard error of each mean presented in parentheses. Means are in degrees.

*Significantly different from frequencies of two or four times per week ($p < .05$).

Table 3

Adjusted Means for Simple and Main Effects for Control Leg Posttraining Straight Leg Raise Flexibility

Duration (seconds)	Frequency (times/week) 2	4	6	Main Effect M for Duration
30	88.27 (1.97)	85.67 (1.75)	83.86 (1.78)	85.93 (1.02)
60	88.12 (1.86)	87.13 (1.80)	88.47 (1.80)	87.91 (1.13)
90	84.84 (1.74)	92.11 (1.90)	88.08 (2.07)	88.34 (1.02)
120	93.84 (1.75)	84.85 (1.76)	88.96 (1.81)	89.22 (1.01)
Main Effect M for Frequency	88.77 (0.94)	87.44 (0.90)	87.34 (0.88)	

Note. Standard error of each mean presented in parentheses. Means are in degrees. No significant differences between main effect means were seen for either frequency or duration.

Table 4

ANCOVA for Posttraining Knee Extension with Initial Flexibility

ANCOVA Summary Table

Source of Variance	Partial SS	df	MS	F
Frequency	16.92	2	8.46	0.16
Duration	53.66	3	17.89	0.33
Frequency x Duration	200.68	6	33.45	0.62
Error A	1285.29	24	53.55	
Initial Flexibility	6.44	1	6.44	0.53
Leg (Control or Treatment)	43.23	1	43.23	3.54
Frequency x Leg	38.49	2	19.25	1.58
Duration x Leg	1.42	3	0.47	0.04
Frequency x Duration x Leg	61.75	6	10.29	0.84
Error B	280.56	23	12.20	

Table 5

Nonadjusted Means for Simple and Main Effects for Treatment Leg Posttraining Knee Extension Flexibility

Duration (seconds)	Frequency (times/week) 2	4	6	Main Effect M for Duration
30	130.00 (2.00)	127.00 (2.00)	132.67 (2.00)	129.89 (1.15)
60	127.00 (2.00)	134.00 (2.00)	134.33 (2.00)	131.78 (1.15)
90	129.00 (2.00)	127.00 (2.00)	130.00 (2.00)	128.44 (1.15)
120	126.33 (2.00)	131.00 (2.00)	133.67 (2.00)	130.33 (1.15)
Main Effect M for Frequency	127.92 (0.99)	129.75 (0.99)	132.67 (0.99)	

Note. Standard error of each mean presented in parentheses. Means are in degrees. No significant differences between main effect means were seen for either frequency or duration.

Table 6

Nonadjusted Means for Simple and Main Effects for Control Leg Posttraining Knee Extension Flexibility

Duration (seconds)	Frequency (times/week) 2	4	6	Main Effect M for Duration
30	128.33 (2.00)	125.67 (2.00)	130.67 (2.00)	128.22 (1.15)
60	127.67 (2.00)	132.33 (2.00)	129.67 (2.00)	129.89 (1.15)
90	127.00 (2.00)	122.67 (2.00)	131.67 (2.00)	127.78 (1.15)
120	128.67 (2.00)	131.00 (2.00)	126.67 (2.00)	128.78 (1.15)
Main Effect M for Frequency	128.42 (0.99)	127.92 (0.99)	129.67 (0.99)	

Note. Standard error of each mean presented in parentheses. Means are in degrees. No significant differences between main effect means were seen for either frequency or duration.

Reliability Coefficients

Intratester reliability coefficients for the initial flexibility measures were .95 for the straight leg raise test and .94 for the knee extension test. Coefficients performed on the posttraining scores revealed <u>R</u> values of .95 for both methods of measurement.

Chapter 5

DISCUSSION

This study examined the effect of flexibility training of different frequencies and durations on hamstring flexibility. Durations of 30, 60, 90, and 120 s and frequencies of two, four, and six times per week were examined. Two different types of measurement techniques were used in assessing hamstring flexibility. This chapter will discuss how varying frequency and duration affected hamstring flexibility when measured by the passive straight leg raise test, and present explanations for the difference in results obtained with the passive knee extension test.

Frequency and Duration Effects

Results from data obtained through measurement of hamstring flexibility using the passive straight leg raise test revealed that training with static stretching increased hamstring flexibility. At all levels of duration and two levels of frequency the treatment leg displayed significantly greater posttraining levels of flexibility than the control leg.

When the frequency effects were analyzed, the data demonstrated that as the frequency of performance increased, flexibility increased. For each additional day of stretching a 1.75° increase in flexibility resulted. A frequency of six times per week was shown to be more beneficial than four, which was in turn more beneficial than two. A frequency of two times per week displayed no significant effect. These findings agree with the work of Wallin et al. (1985), who examined the effects of varying frequencies on passive flexibility. In subjects who had been training for 30 days, it was found that one time a week was enough to maintain flexibility, while three and five times per week further increased range of motion. A frequency of five was shown to be the most beneficial. As the present study did not examine the effects of frequency on trained individuals, it is not known whether the two times per week frequency would be adequate to maintain range of motion.

Based upon the present study, it appears that training somewhere between two and four times per week can cause an increase in the flexibility of an untrained individual, and that increasing frequency farther will result in a further increase in range of motion. In contrast, a study using frequencies of two, three, or four times per week showed all to increase the flexibility of ankle plantar- and dorsiflexors equally (McIntyre, 1987). It was not reported whether range of motion was measured actively or passively or what the extent of the training was. Therefore, it is difficult to speculate as to why these findings are different from other studies.

From the examination of the effects of duration in the present study it was determined that increasing duration of the stretch beyond 30 s did not further enhance flexibility. This indicates that the increase in flexibility occurred using a training duration of 30 s. Although previous studies have not been performed on duration of stretching in flexibility training, these results are in agreement with studies concerning the acute effects of stretching at different durations upon flexibility. Madding et al. (1987) studied the effect of duration on acute passive hip abduction range of motion. Durations used were 15, 45, and 120 s. They found all three durations increased the range of motion but no difference existed among the three groups. Fox (1984) investigated the effect of performing static hamstring stretching with different durations on acute, active flexibility. He used durations of 5, 15, 30, 60, and 120 s. His results indicated no effect on flexibility at the 5-s duration, but a significant increase at 15. No differences existed among the 15- to 60-s groups. A significant increase from the other times was seen with the 120-s duration. This increase seen at a duration of 120 s, not seen in Madding et al. (1987), may have been due to methodological differences between the studies. Because the present study examined training adaptations but not acute effects, it is not clear how this duration would have affected subjects on an acute bout of stretching. Through careful evaluation of the data of Fox and Madding et al., it was apparent that the largest increase in flexibility occurred with durations between 5-15 s. Past this point, Fox's data showed a linear trend for flexibility to continue increasing with increasing duration, but with much smaller increments. Several other studies that examined static stretching have supported this finding, in that durations of 6-9 s have been shown to increase range of motion (Medeiros et al., 1977; Moore & Hutton, 1980; Tanigawa, 1972).

The results from the present study demonstrated that for static stretching to improve flexibility a training duration of 30 s was required. Other studies that examined acute effects of stretching determined that a stretch between 6 and 15 s was necessary. As the present study did not examine durations less than 30 s, it is unknown if training durations between 0 and 30 s will cause an adaptation in flexibility.

In the present study, flexibility training over a 1-month period of time significantly increased hamstring flexibility in previously untrained individuals. As compared with other studies, these results represent training adaptations rather than acute effects. A duration of 30 s and a frequency of 4 times per week were required to produce this adaptation. Although the mechanisms underlying these changes were not studied, these gains in flexibility may have been due to a mechanical stretching of the connective tissue. A long duration stretch has proven to be beneficial in effecting changes in collagenous connective tissue (Lehman et al., 1970; Warren et al., 1976), however, the minimum stretching time needed to produce this change has not been established. It is possible that a stretch performed at some intermediate duration between 0 and 30 s could effect this change. It has also been stated that connective tissue is progressively shortening and thickening when not opposed by a stretching force and that to maintain normal mobility, joints must be routinely taken through their full range of motion (Barnes, 1984; Kottke et al., 1966; Sapega et al., 1981). The duration and frequency of stretch employed in this study may have been ample to overcome this remodeling force and allow the muscles involved to achieve a greater amount of flexibility.

Both Fox (1984) and Tanigawa (1972) offered another theory on why static stretching may allow increased range of motion. They suggested that Golgi tendon organs may be stimulated during static stretching, which would then cause inhibition of tonic muscle activity and allow greater stretch. It is doubtful though, that Golgi tendon organs would have any influence on inhibiting the muscle during passive stretch, as these are much more responsive to active contraction than passive tension (A. J. Robinson, personal communication, August 4, 1987). In addition, Fox suggested that the muscle spindle, which is responsible for activating the stretch reflex, may be inhibited during a 15-s stretch. This would allow the muscle to relax and allow further lengthening. If a stretch were truly static with no additional changes in muscle length taking place, it may be possible for the muscle spindle to adapt and decrease its firing. This is highly unlikely, however, as a subject typically continues to lengthen the muscle during a static stretch. In addition, the attenuated response of the muscle spindle would probably not allow a greater stretch to occur (A. J. Robinson, personal communication, August 4, 1987).

In summarizing the present study and previous work, it appears that to effect an increase in flexibility a training duration between 5 and 30 s, and a frequency of at least four times per week is needed. Further gains in flexibility can be observed with greater frequencies of training (four or six times per week). The mechanism underlying an enhanced posttraining range of motion is not completely understood, however the connective tissue may be the affected structure that allows more stretch to occur.

Testing Methods

In this study two methods of testing were used to assess hamstring flexibility. These were a passive straight leg raise test and a passive knee extension test. Results obtained from these tests revealed different conclusions. Whereas the straight leg raise test displayed a significant training effect, the knee extension test showed no posttraining improvement in range of motion. This section will discuss possible reasons for this discrepancy.

When performing a straight leg raise, the motion consists of several component motions. These include hip flexion, posterior pelvic tilting, and lumbar flexion (Norkin & Levangie, 1983). As the knee is kept extended, the hamstrings are put on a stretch over both the knee and hip joints during this motion. In addition, the gluteals and low back erector spinae are stretched during this motion. In an attempt to eliminate or decrease the amount of pelvic tilting and lumbar motion, several authors proposed stabilizing the pelvis and thereby localizing the stretch to the hamstring muscles (Fisk, 1979; Tanigawa, 1972; Wallin et al., 1985). However, Bohannon (1982) used cinematography to compare increases in the angle of a straight leg raise with the horizontal to increases in relation to the pelvis and found that although the pelvis was stabilized, it rotated during the straight leg raise. Over the period of the stretch, the pelvic angle increased a mean of 24.9°. He concluded that this test does provide a relative indication of hamstring length, but in addition measures the flexibility of other structures as well. In response to this, Gajdosik and Lusin (1983) designed a test they believed was more objective for measuring pure hamstring tightness. The test was the active knee extension test, in which the end point of hamstring tightness is measured by the angle of knee extension and the hip is fixed in place at 90°. Gajdosik and Lusin believed the knee extension test is much more specific to the hamstring muscles because these muscles are isolated with this test. In the present study a similar knee extension test was used, except that it was performed passively and a different method for determining the end point of hamstring tightness was used.

Flexibility training has been shown to be specific in nature (Beaulieu, 1980; Harris, 1969). That is, training will increase flexibility of the stretched joint, but will not affect the flexibility of untrained areas. In the present study, hamstring stretching was done such that the subject performed hip flexion with the knee in extension, pelvic tilting, and lumbar flexion, as in the straight leg raise test. The amount of lumbar flexion was minimized as much as possible by having subjects try to keep their backs in extension, and all subjects did report the stretch to be within the hamstring group. However, motion still occurred at the pelvis and lumbar spine, placing an additional stretch on the gluteals and low back erector spinae. Therefore, it seems reasonable that what was specifically stretched did show an increase in flexibility when measured in a position very similar to the stretching method (using the straight leg test). The knee extension test in the present study, if truly more specific to the hamstring muscles, did not distinguish a difference between pre- and posttraining range of motion, indicating no statistically detectable improvement in the isolated hamstring muscle. Perhaps if training involved stretching using a knee extension method with the hip fixed at 90°, an adaptation specific to the hamstrings would have been detected using the knee extension method.

In conclusion, it appears that the different results obtained from the two testing methods may be a result of the straight leg raise more specifically assessing the trained anatomical structures. With training, adaptations took place in the hamstrings, gluteals, and erector spinae muscles. The additive effect of increased range of motion in all these muscles was displayed through a significant increase in the straight leg raise flexibility. The passive knee extension test may have displayed significant results if a stretching procedure that more specifically affected the hamstrings had been used. Although some increase in hamstring flexibility may have occurred with the training technique used, the isolated effects upon the hamstrings were not sufficient to elicit an increase in hamstring range of motion alone.

Summary

In the present study flexibility was seen to increase when measured by the passive straight leg raise test. A frequency of four times per week was shown to be beneficial, with greater frequency resulting in more benefit. Increasing the duration over the minimum time of 30 s did not further increase flexibility. When combined with past data, it appears that a frequency of at least four times per week is needed to increase flexibility and that with increasing frequency flexibility adaptations are greater. This increase in flexibility probably occurred in the hamstrings, gluteals, and low back erector spinae rather than solely in the hamstring muscles. The passive knee extension test, also used in this study, may not have been sensitive to the alteration in flexibility because of the test's selective assessment of hamstring range of motion.

Chapter 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS FOR FURTHER STUDY

Summary

The purpose of this study was to examine the effects of a selected combination of frequencies and durations of stretching on hamstring muscle flexibility. Stretching was performed for 4 weeks by 36 college-aged, female subjects, and a split-unit, repeated measures design was utilized. The dominant lower extremity of each subject received the stretching treatment, while the contralateral limb served as the control. Subjects were divided into 12 groups with durations of 30, 60, 90, and 120 s and frequencies of two, four, or six times per week examined in all possible combinations.

Hamstring flexibility was measured passively by two different methods. These included the straight leg raise test and the knee extension test. Measurement was made 1 day prior to and 2 days after the training period. Training involved static self-stretching performed by the subject placing the treatment leg on a plinth and leaning forward to stretch the hamstrings while the knee was extended. Prior to stretching, all subjects performed a warmup of jogging in place for 5 min.

An ANCOVA used to analyze posttraining straight leg raise flexibility demonstrated initial flexibility (covariate), leg (treatment vs control), and the frequency x leg interaction to all be significant ($p < .05$). A linear contrast performed for frequency exhibited a significant linear relationship between frequency and posttraining flexibility, such that for each additional day of training a 1.75° increase in flexibility occurred. Linear contrasts for duration showed no significant effect on posttraining flexibility over the range of 30 to 120 s. There was, however, a significant difference between the treated and control legs for duration across all levels. Simple main effects for the adjusted means of the treated and control legs were examined with individual *t* tests. For frequency, the treatment leg displayed significantly greater flexibility with six times per week than with either two or four times per week. In addition, four times per week resulted in greater flexibility than two times, while two times was not significantly different from the control leg. No significant difference existed between duration means for either leg.

An ANCOVA performed upon the knee extension flexibility data revealed no significant effects. This may have been due to this being a more specific test of hamstring flexibility than the straight leg raise test. The type of stretch performed involved not only hamstring stretching, but gluteal and low back stretching as well. This type of stretch closely resembled the testing position used in the straight leg raise test. The straight leg raise test therefore, may have been more specific to the training technique.

Conclusions

Based upon analysis of data obtained from the straight leg raise test in the present study, the following conclusions can be made:

1. Flexibility training utilizing durations of 30, 60, 90, or 120 s and frequencies of either four or six times per week resulted in significantly greater hamstring flexibility in the treated than in the control leg.

2. Frequency displayed a significant linear trend for flexibility to increase as frequency increased, with a frequency of six times per week being more beneficial than either four or two. This demonstrates that greater frequency results in greater gains in chronic flexibility.

3. A frequency of two times per week displayed no significant effect upon posttraining flexibility. Four times per week, therefore, may be the minimum frequency needed to increase range of motion.

4. No significant difference existed among the duration means for either the treated or control leg, indicating that a 30-s duration is adequate for increasing chronic range of motion.

5. The passive straight leg raise test and knee extension test may have displayed conflicting results because they were measuring different structures, with the straight leg raise test more specifically measuring the trained structures.

Recommendations for Further Study

Based upon results obtained in the present study, the following recommendations are made:

1. A study should be performed that examines the effects

of training with durations between 0 and 30 s on flexibility.

2. A study should be performed utilizing different combinations of frequencies and durations to examine how long effects remain both in acute bouts of stretching and in flexibility training.

3. A study should be performed that examines frequencies of 1 through 7 days per week on maintaining and improving flexibility.

4. A study should be performed that utilizes one assessment method of flexibility done both actively and passively to ascertain if differences result.

5. A study should be performed that utilizes a specific type of stretch that is similar to the knee extension test, to see if this increases flexibility as measured by this test.

6. A more objective way of determining the end point in the range of motion needs to be developed and utilized when assessing flexibility.

Appendix A

INFORMED CONSENT FORM

1. a) Purpose of the study. To determine the effects of different frequencies and durations of stretching on hamstring muscle flexibility.

b) Benefits. This study will help to provide information as to the best frequency and duration to use when performing stretching exercises.

2. Method. Your hamstring flexibility will be measured by two methods. First, your leg will be passively raised while you lie on your back. Your knee will be kept straight while the whole leg is raised, and the number of degrees it can be raised will be recorded. This will be repeated two more times. Second, while lying on your back your hip will be placed at a 90° angle, your knee will then be passively straightened, and the number of degrees your leg is raised will again be recorded. This will also be repeated two more times. Then the entire procedure will be repeated with your other leg. Your hamstring flexibility will be measured once before you begin your stretching program and once at the completion of your 4 weeks of stretching.

After your flexibility has been measured, you will be randomly placed into 1 of 12 groups. All the groups will perform the same stretching exercise, but you will be performing them either two, four, or six times per week and will be holding the stretch for either 30, 60, 90, or 120 seconds. To perform the stretch you will sit on a table with your leg placed straight out in front of you. You will then lean forward until you feel a slight stretch in the back of your thigh. You will be asked to rate the amount of discomfort you felt following each stretch. All groups will jog in place for 5 minutes prior to every stretching treatment.

3. Will this hurt? No, this will not hurt. Stretching should be performed so that only a mild stretch is felt; it should not be taken to the point of pain.

4. Need more information? Contact Amira Ranney, Physical Therapy Department, Smiddy Hall, 274-3716, or Dr. G. A. Sforzo, Exercise and Sport Sciences, 274-3359.

5. Withdrawal from the study? You will be free to withdraw from the study at any time. Your academic status will in no way be affected by your participation or nonparticipation in this study.

Initial:_______________

6. <u>Will these data be maintained in confidence</u>? You will not be personally identified by name, initials, or any other means during the interpretation and publication of these data.

7. I have read the above, I understand its contents, and I agree to participate in the study. I acknowledge that I am 18 years of age or older.

______________________________ ________________________

Signature Date

Appendix B

INSTRUCTIONS FOR PARTICIPANTS IN STRETCHING RESEARCH

1. Once you begin your stretching program, it is very important that you do not alter any present exercise routines or activity.

2. Do not begin any new stretching exercises or stretch your other leg during this 4-week stretching program.

3. If you do exercise regularly, try to do it at the same time every day. Do not exercise immediately before you come for your stretching program.

4. Please keep a log of any physical activity you do during this 4-week period.

5. If you know you are going to miss a session, please let me know ahead of time so arrangements can be made for you to stretch on your own. If you do not know ahead of time that you are going to miss, please call me anyway. It is very important that each stretching session is done, whether here or at home. HERE (SH213) is preferable. My number is: 274-3716.

6. Each day that you stretch you will be asked to:

   a) Jog in place for 5 minutes.
   b) Stretch one leg for a designated amount of time.
   c) Mark a visual analogue scale to report the amount of pain or discomfort you felt while stretching.
   d) Mark where you felt a stretch occurring.

THANK YOU VERY MUCH FOR YOUR HELP IN THIS STUDY

Stretching Instructions

1. Place leg to be stretched on table with the knee straight, foot relaxed, and toes and kneecap pointing straight towards the ceiling. You should be sitting on the table with the other foot on the floor.

2. Place both hands behind your head with elbows back as far as possible.

3. Keeping your back as straight as possible lean forward until a slight stretch is felt in the back of your thigh. Stretch should not be felt in your calf or back.

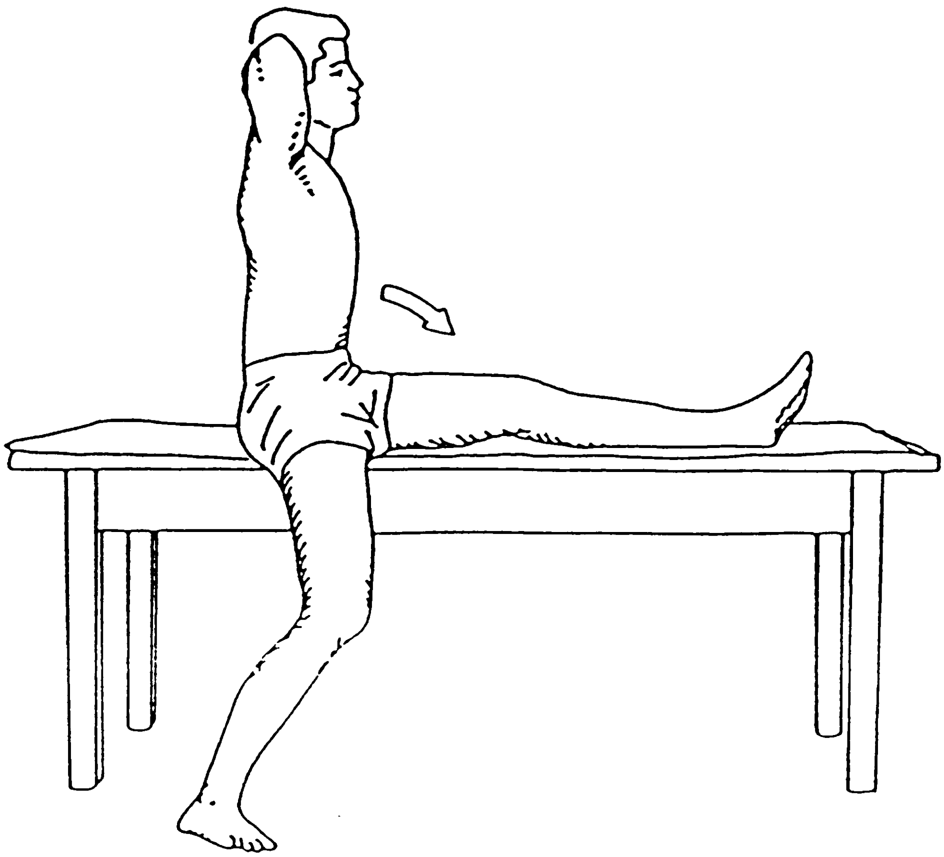
4. Hold the stretch for your designated amount of time. The stretch should not be painful, but should feel like a mild pull. As this pull subsides during the stretch, stretch slightly farther until the same amount of stretch is once again felt.

5. Breath normally throughout the stretch.

6. At the end of the stretch, return to the upright position or bend your knee slightly so that no stretch is felt. Rest in this position for 5 seconds, and then we will repeat the stretch.

7. Fill out a visual analogue scale as to the amount of pain you felt during the stretch.

8. Fill out the diagram as to where you felt the stretch.



Appendix C

DISCOMFORT RATING

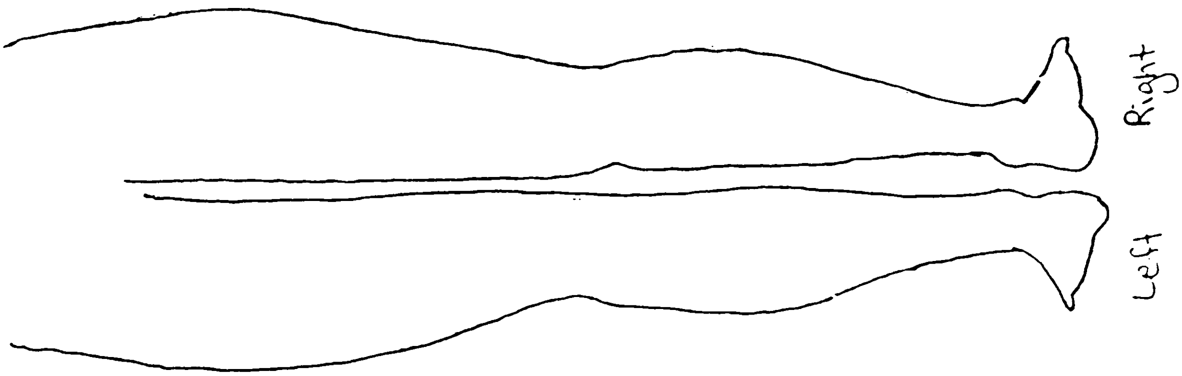
Name________________________________ Date________________________

The left end of this scale represents no pain.
The right end of this scale represents all the pain you can imagine.

Please mark on the scale the amount of pain you felt while stretching.

____

Please mark where you felt the stretch occur while stretching.



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